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Minnesota Walleye: How the State's Current Fishing Culture is Detrimental to Minnesota's Aquatic Ecosystems and How It Can Change

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ENVR 395

Advisors: Jean Lavigne & Joseph Storlien

Abstract

This study explores Minnesota's current angling culture and how it may be detrimental to aquatic ecosystems. The state's current angling culture is centered around catching walleye (*Sander vitreus)*, the state fish. The species has rightfully earned its reputation amongst anglers, but the impacts associated with its popularity may be negative. This research looks primarily at which factors of the angling culture are detrimental and where anglers and fisheries managers need to make improvements. The current motivations and practices of anglers cannot continue, as walleye abundance is on the decline due to angling pressure and hydrological changes. Walleye are not the problem, but rather the collective act of aggressive species-specific angling. The purpose of this study is to find solutions that will lead to the change of perceptions and practices in the angling community. These solutions will need to include efforts from both anglers and fisheries agencies to increase angler knowledge through education, increase the regulation of walleye and other sensitive species, and incentivize other species. These will help anglers move from targeting only one species to fishing for multiple species with the motivation for having an outdoor experience. There are many obstacles to these solutions since walleye drives angler participation and maintains agency trust. However, once an angler culture shift is accomplished our lake resources will transition from being commodities to healthy fisheries for future generations.

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Introduction

Minnesota, famously known as "The Land of 10,000 Lakes," is a state in the Upper Midwest that is most commonly recognized by non-residents for its cold temperatures and its expansive wilderness. Beyond these common views of the state, rich culture and history can be found here. This state is home to diverse ecosystems and geography, as well as its prairies, forests, and lakes. Along with these physical aspects, history and prowess in the industries of mining, forestry, and agriculture are also found here. Part of Minnesota's heritage is the strong connection between the land and the people. Outdoor recreation and experiences are an important part of the lives of Minnesotans. One of the most popular outdoor activities amongst Americans is fishing, with 49 million participants nationwide.[1] "No other state has experienced the impact fishing has had like it has in Minnesota in terms of economy, heritage, and history."[2] A pastime that has been popular for generations, fishing has brought Minnesotans together to appreciate the natural world and to utilize the abundant natural resources of the state. When people in Minnesota think of fishing, they most likely think of walleye. Walleye is undoubtedly the most prized fish amongst anglers and has even claimed its title as the state fish.[3] The walleye rightfully earned its place in the eyes of Minnesota anglers, but how did the walleye go from being just another species of fish to becoming a cultural symbol?

A spike in walleye awareness amongst anglers in the 1950s was attributed to the availability of new technologies, beginning a "snowball effect" in the angling community. More

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[1] S. Lock, "Outdoor Participation: Most Popular Activities Us 2018 | Statista," ed. Statista (2020).

[2] Minnesota Fishing Museum and Hall of Fame, "Minnesota Fishing Museum," https://www.fishinghalloffamemn.com/sample-page/minnesota-fishing-museum/.

[3] Office of the Minnesota Secretary of State, "Office of the State of Minnesota Secretary of State," http://www.sos.state.mn.us/about-minnesota/state-symbols/state-fish-walleye/.

and more anglers joined in on targeting walleye, learning of its great taste, its large size, and its challenging but rewarding angling experience. Other large predatory fish – northern pike and muskellunge – were popular in the trophy fishing community but were not a popular choice for anglers that fished for food. Walleye had the size and challenge of northern pike and muskellunge fishing while being a great-tasting and rewarding catch. Walleye are also relatively easy to filet and cook. The tradition of walleye fishing has been passed on through generations, being a staple to most anglers' reason to fish. Minnesota anglers collectively agree upon its importance to the fishing community. The angling culture in Minnesota has since developed to favor and support this species.

This development of the angling culture and desire to catch more walleye led to fisheries managers playing a more important role in assuring angler satisfaction. In a state with abundant water resources and walleye availability, the demand for walleye and other fishing experiences can fund fisheries managers to manage and monitor lakes and their fish populations. Management of walleye was and still is one of the most important tasks for fisheries managers since the demand for walleye drives funding and keeps angling interest in the state high. Stocking is particularly the most popular and effective strategy since it keeps populations of walleye relatively high and allows anglers to keep catching walleye faster than they can reproduce without stocking efforts.

The shift in angling culture to favor walleye was beneficial for the state in terms of employing fisheries managers, funding natural resource management organizations, and allowing Minnesotans to experience the outdoors, but the management strategies were and still are reflective of what anglers find to be most important: their catch.

Research Motivations

The motivation to study this topic and conduct this research began while working for the Minnesota Department of Natural Resources in the summer of 2019. I was an intern within the Division of Fish and Wildlife, working specifically as a Fisheries IBI intern. My work entailed conducting fisheries surveys and analysis of lakeshore habitat and development. Fisheries IBI, or index of biological integrity, collects data on pollution-intolerant species of fish and can "score" lakes on their overall biotic health based on the fish community in a lake in conjunction with lakeshore development surveys and water quality data from the Minnesota Pollution Control Agency. I have always been interested in the monitoring and protection of sensitive species that are important for the integrity of lakes, but during my internship I also learned a significant amount about the angling community in terms of their priorities and knowledge of fisheries and aquatic ecology.

While surveying lakes, encountering homeowners and anglers was common. Maintaining good relations with the angling community and general public are priorities of the Minnesota DNR, so making conversation with these people during encounters on lakes was important. Many encounters involved an angler or homeowner asking who we were and what research we were doing on the lake. After hearing that we were from the Minnesota DNR and that we were assessing the lake's fishery, the next question was almost always along the lines of how the walleye were doing or if we were there to stock more walleye. They also were unaware of many of the species we had found when we presented our findings or were not pleased to hear that we had encountered species that were not game species, in many cases. It became apparent to me that a majority of the anglers and homeowners on Minnesota lakes value walleye and have little awareness of other species, particularly non-game species. It shocked me to see first-hand how

important a diverse fish community is for a lake's health, but also see a majority of anglers and homeowners that live and depend on Minnesota lakes have little awareness of what a healthy lake was defined as. Walleye reigned supreme over all other species and having walleye abundance was a bigger concern for anglers than the biotic integrity of the lake.

I wanted to see why this is the case with what appeared to be most anglers and homeowners. Walleye are an important and popular natural resource in Minnesota, but I wanted to see if this collective craze for walleye and lack of knowledge of other species and lake health were detrimental to Minnesota's aquatic ecosystems. My internship experience was incredible, and I learned a substantial amount about aquatic ecology, ichthyology, lake biological integrity, indicator species, and the impacts lakeshore development and other influences have on the fish community. The degradation of Minnesota lakes is on the rise, meaning once healthy and viable fisheries may no longer be able to be utilized by anglers like they once were. Hopefully, this research can shed light on the issues surrounding angler dependence on walleye and can provide solutions and recommendations for the future of fisheries management and angler behavior and motivations. Minnesota's lakes are incredible resources for outdoor recreation and are biologically and aesthetically important. Protecting them in terms of keeping them viable for angling without sacrificing their biological integrity will an important goal for fisheries managers and anglers alike in the future.

Overarching Problems

Walleye (*Sander vitreus*) are a freshwater fish in the perch family, characterized by their gold and olive-colored body, a back crossed with five or more black bands, and two dorsal fins – one spiny and one soft-rayed (Figure 1).[4] Walleye are most notable for their opaque, silver eyes and their huge mouth with large canine teeth.[5]

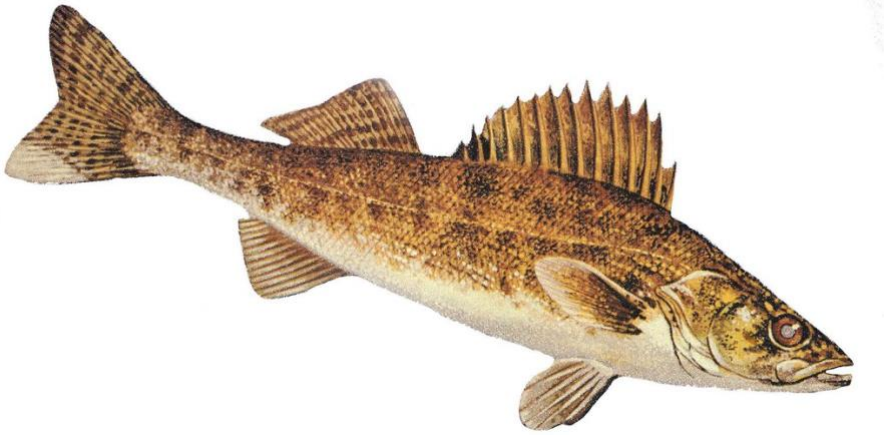

Figure 1. Side-view of walleye (*Sander vitreus*). "Walleye (*Stizostedion vitreum vitreum*)" by NOAA Great Lakes Environmental Research Laboratory is licensed under CC BY-SA 2.0.

This species is native to most of North America, found in the St. Lawrence-Great Lakes, Arctic, and Mississippi River basins.[6] Walleye can live in most settings but prefer cool, deep, and quiet waters.[7] Being nocturnal feeders, they rely on a light-sensitive membrane in their eye called the tapetum lucidum that allows them to hunt in the dark.[8] Their "night vision" ability allows them to hunt in low-light conditions – typically feeding in shallow waters at night and spending the day in deeper water – making them advantageous in water with lower clarity compared to other

[4] National Wildlife Federation, "Walleye," https://www.nwf.org/Home/Educational-Resources/Wildlife-Guide/Fish/Walleye.
[5] Lawrence M. Page and Brooks M. Burr, *Peterson Field Guide to Freshwater Fishes of North America North of Mexico*, 2 ed., Peterson Field Guides (Houghton Mifflin Harcourt, 2011), 86.
[6] Ibid., 508-10.
[7] National Wildlife Federation, "Walleye."
[8] Wisconsin Department of Natural Resources, "Walleye," ed. Bureau of Fisheries Management (2008), 2.

fish that do not have the light-sensitivity that walleye have.[9] In terms of reproduction, walleye reach sexual maturity at age two, for males, and age four, for females.[10]

> An average of 50,000 eggs are laid by a female in a year, typically in the spring, with no protection provided to the eggs by the parents. The eggs hatch between seven and 21 days, depending on water temperature. The fry, or the new-born walleye, must reach a food source within three to five days or they will perish. At this stage of their life, their fins aren't developed and must rely on currents for movement.[11]

The diet for walleye fry is zooplankton due to their size, but their diet transitions to include smaller fish, insect larvae, and aquatic invertebrates in adulthood.[12] Though walleye may have it difficult as fry, they can grow to be large predators of Minnesota lakes (Table 1).

Table 1. Average length and weight of Walleye (*Sander vitreus*) by age. Taken from the Wisconsin Department of Natural Resources (2008).[13]

Age (yrs.)	**Length** (in.)	**Weight**
1	5	0.7 oz.
2	10	5.4 oz.
3	14	1.45 lbs.
4	19	2.14 lbs.
5	21	4
6	23	5.2
7	26	6

Walleye are undoubtedly the number one prized fish amongst anglers in Minnesota, but this has not always been the case. It was not until the late 1950s, with the invention of monofilament fishing line and depth locators, that walleye started getting the attention of anglers.[14] Anglers traditionally targeted fish like pan fishes and northern pike since these fish could be targeted with the tactics and equipment of the time. Historically, walleye were elusive

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9 Ibid.
10 Ibid., 3.
11 Ibid.
12 Ibid.
13 "Walleye," ed. Bureau of Fisheries Management (Wisconsin DNR, 2008).
14 Dan Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'," *MPR News* 2018.

to the eyes of anglers. Walleye, typically living in the depths of lakes, could not be targeted as easily as they can be today. The obstacles to locating and catching walleye and the low awareness of the species amongst anglers were to blame for the little effort and interest from anglers to target walleye. With little interest or awareness in the species, there was not an incentive for anglers to attempt catching it. However, with these new technologies, the species was no longer as elusive to anglers. Depth locators helped anglers pinpoint walleye on lake bottoms and monofilament line had the strength and transparency that traditional line lacked. Monofilament line made it harder for walleye to notice the line before being caught and lessened the chances of a walleye breaking off during reeling. Both of these technologies aided in improving angler success when targeting the species and subsequently resulted in increased awareness and popularity of the species.[15] Walleye quickly gained popularity due to the decrease in difficulty of catching them and the realization of the worthwhile-reward of targeting the species: the unique fishing experience and the great taste of the fish.[16] Once anglers got a taste for walleye, they were hooked.

Today, 7 out of 10 of Minnesota anglers said they target walleye more than any other species while fishing, and in 2019 alone there were 1.4 million fishing license holders in the state.[17] There is a significant proportion of the state's population that participates in fishing and a majority, as it can be assumed, targets walleye. Walleye can often grow up to about three feet in length and weigh up to 10 to 20 pounds, making these great tasting fish a high priority to

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[15] Ibid.

[16] Ibid.

[17] Caroline Carlin, Susan A. Schroeder, and David C. Fulton, "Site Choice among Minnesota Walleye Anglers: The Influence of Resource Conditions, Regulations and Catch Orientation on Lake Preference," *North American Journal of Fisheries Management* 32, no. 2 (2012); US Fish and Wildlife Service, "Historical License Data," ed. USFWS (2020).

anglers.[18] The walleye's size, taste, and accessibility all drive anglers to target walleye over other species. Walleye have been and are still increasingly becoming important as a natural resource, socially and economically. Due to this popularity and demand for walleye, fisheries managers intensively monitor and manage walleye populations.[19] This walleye "craze" accounts for anglers spending considerable resources fishing for walleye and contributing to local and state economies.[20] In 2019 alone, the gross cost of all fishing licenses, tags, permits, and stamp totaled $27.5 million.[21] In Minnesota, anglers contribute a total of $4.2 billion to the state economy.[22] The management of fisheries resources, especially walleye fisheries, have been beneficial to the state and anglers, in terms of economy and outdoor recreation opportunity. The current fishing culture, centered on walleye angling, has been beneficial to our state's economy and getting people to participate in outdoor recreation and utilize our shared natural resources. Walleye are such an important symbol to Minnesotans that the fish is idolized by five different statues around the state (Figure 2).[23]

The current fishing culture is beneficial in several ways, particularly economically and socially. Current walleye management under fisheries managers has not necessarily been detrimental, either. Traditional and imposed management strategies have been great tools in keeping aquatic ecosystems healthy under the pressure of anglers. However, issues can arise around what the majority of anglers believe to be the correct way to manage lakes, as well as the

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[18] National Wildlife Federation, "Walleye."
[19] Brian G. Blackwell, Todd M. Kaufman, and Tyrel S. Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," *Fisheries Research* 216 (2019): 59.
[20] Ibid.
[21] US Fish and Wildlife Service, "Historical License Data."
[22] Minnesota Department of Natural Resources, "Minnesota's Fish Hatchery System," Minnesota DNR, https://www.dnr.state.mn.us/areas/fisheries/hatcheries.html.
[23] Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'." *MPR News* 2018.

collective belief of which species of fish deserve status or care. Fisheries managers are obligated to meet the demands of anglers to maintain adequate funding. Since fisheries managers follow angler demands, doing so perpetuates anglers' belief that their angling desires are not an issue. For the most part, anglers control how fisheries are managed. With anglers continuing to have their biases on which fish are worthy of management and their interest, the angling culture as it is could prove to be detrimental, especially in the future.

Figure 2. A fiberglass walleye statue in Garrison, MN on Mille Lacs Lake. "Newly Refurbished Garrison Walleye" by peterk17700 is licensed under CC BY-SA 3.0.

The current angling culture is focused particularly on what are classified as game species, or species that have commercial or cultural value. This could mean a species has historical or cultural significance, is palatable and desired by anglers, is fun to catch, or is seen as an important attribute of the angling experience. Catch orientation, or the species-selectivity of anglers, is something that influences anglers to target walleye. Catch orientation is attributed to specific factors that make anglers find a species to be desirable. These factors commonly include

"catching something", "catching many fish", "catching big fish", and "keeping fish".[24] These factors are interchangeable, but the summary of catch orientation is that anglers are more interested in catching a species of fish that is plentiful, is fun to reel in, and tastes good. Fish species known as game species are classified as such because they fall under at least one of these categories. Anglers are more likely to prioritize such species since these species are the only ones that have angler-perceived value. Walleye are particularly the most valuable to anglers, as seen by its current demand, since the species falls into all categories of being potentially valuable to anglers. In terms of management, anglers are particularly concerned about game fish populations remaining abundant. Anglers are willing to pay to have walleye stocking implemented on their lakes for a chance at catching more walleye. Along with this, the future of angling is likely to be impacted by and may have to change due to threats like climate change, increased angling pressure, invasive species, lake development, and water pollution.[25] "Collectively, the long-term impacts of these stressors on fish communities and individual species are not well documented, especially at a comprehensive, statewide scale."[26] These anthropogenic stressors will likely have long-term impacts on aquatic systems and subsequently change the abundances of fish species that anglers typically catch, including walleye.

Another issue with the current angling culture is that other species that are crucial to the biological integrity of aquatic ecosystems are given less priority compared to walleye. This can be seen in the allocation of lake management efforts towards improving the angler experience

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[24] Susan A. Schroeder and David C. Fulton, "Comparing Catch Orientation among Minnesota Walleye, Northern Pike, and Bass Anglers," *Human Dimensions of Wildlife* 18, no. 5 (2013): 355.
[25] Bethany J. Bethke and David F. Staples, "Changes in Relative Abundance of Several Minnesota Fishes from 1970 to 2013," *Transactions of the American Fisheries Society* 144, no. 1 (2015): 68.
[26] Ibid., 79.

and success with game species since that is where fisheries management funding comes from. Without angler support, fisheries managers would not be able to perform management at its current scale. Therefore, fisheries managers are obligated to focus on what keeps angler support. This, then, drives a cycle of anglers putting a focus on game species, fisheries managers putting a majority of efforts into the management of such species, and anglers seeing more focus on and success with game species. Ultimately, anglers find themselves becoming more interested and focused on only the species of fish that they want to catch, leaving out other potential targets for anglers or biologically important species. The lack of knowledge of non-game species, dependence on walleye, and the threat of future change to aquatic systems all pose an argument that angler knowledge and behavior and fisheries management efforts need to change to put lake ecosystems before angler interest. The angler culture's bias towards walleye is potentially problematic to aquatic ecosystems and is bound to be even more so in the future. Monitoring and managing healthy lakes by prioritizing all fish species and modifying the angling culture, all while keeping angling participation high, will need to happen collectively. This will be a great challenge since culture and tradition in any context are difficult to change. The angling community in Minnesota is built upon this traditional view of angling and our state's heritage of walleye fishing. Though this may be the biggest challenge in changing the angling culture, a conversion in angler interests will benefit anglers, fisheries management efforts, and the environment in the long-run. Doing so will also fulfill our duty to responsibly manage our natural resources.

Current Management Strategies

Walleye are naturally occurring fish in many aquatic systems in the Midwest. They are a predatory fish, keeping populations of smaller fish and aquatic vertebrates in check, but are not necessarily a destructive species. Walleye populations are kept in check because they compete for food resources with other fish like northern pike, muskellunge, and bass species.[27] In lake systems where walleye are naturally occurring, they carry out natural reproduction and face competition from other species. When angling is permitted in such systems, the pressure from anglers to catch walleye may reduce walleye numbers and limit reproduction, in all leaving fewer walleye for other anglers to catch and fewer walleye to compete for resources with other fish. This leads to fisheries management having to manipulate the system so that walleye populations stay balanced. This must be done considering angling pressure, populations of other predators, and food availability. When anglers put little pressure on a walleye fishery or the system has fishing regulations to prevent overfishing, meaning anglers catch walleye at a rate that allows natural reproduction to maintain a healthy population, then there is little need to artificially increase walleye population size. However, walleye fisheries are very likely to be exploited and heavily fished by anglers when given the opportunity.[28]

The massive demand for walleye influences fisheries managers to implement stocking efforts, funded by anglers' fishing license sales. The demand is so high that half of the state's stocking budget goes towards walleye hatcheries and stocking alone.[29] Other management

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[27] Andrew H. Fayram, Michael J. Hansen, and Timothy J. Ehlinger, "Interactions between Walleyes and Four Fish Species with Implications for Walleye Stocking," *North American Journal of Fisheries Management* 25, no. 4 (2005): 1321.
[28] Blackwell, Kaufman, and Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," 60.
[29] Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'." *MPR News* 2018.

practices are effective as well, but stocking is often advocated by stakeholders in response to declining fish populations or angler dissatisfaction.[30] Stocking can be an effective and safe management strategy in walleye fisheries, keeping populations steady for anglers to utilize by counteracting angling pressure. In Minnesota, walleye are stocked regularly in about 900 lakes to maintain viable fisheries for anglers.[31] To get an idea of how significant the stocking effort is, 2.7 million walleye fingerlings were stocked in Minnesota lakes in 2014.[32] The Minnesota Department of Natural Resources has fisheries management offices and hatcheries that support the stocking effort and lake management (Figure 3). These are spread across the state and each fisheries area office oversees all fisheries operations on the lakes within their respective area.

Despite the amount of stocking that fisheries managers implement, natural reproduction still accounts for 85% of harvested walleye in Minnesota.[33] Though stocking can be a sustainable method for maintaining healthy and stable walleye fisheries, there are several potential issues associated with it. These issues with stocking include indirect and direct risks to ecosystems.

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[30] Susan A. Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," *Environmental Management* 62, no. 4 (2018): 668.

[31] Minnesota Department of Natural Resources, "Stock Fish," Minnesota DNR, https://www.dnr.state.mn.us/fisheries/management/stock.html.

[32] Jeffrey R. Reed and David F. Staples, "Evaluation of Two Different Stocking Rates of Small Walleye Fingerlings in Minnesota Lakes," *North American Journal of Fisheries Management* 37, no. 6 (2017): 1243.

[33] Peter C. Jacobson and Charles S. Anderson, "Optimal Stocking Densities of Walleye Fingerlings in Minnesota Lakes," Ibid.27, no. 2 (2007): 650.

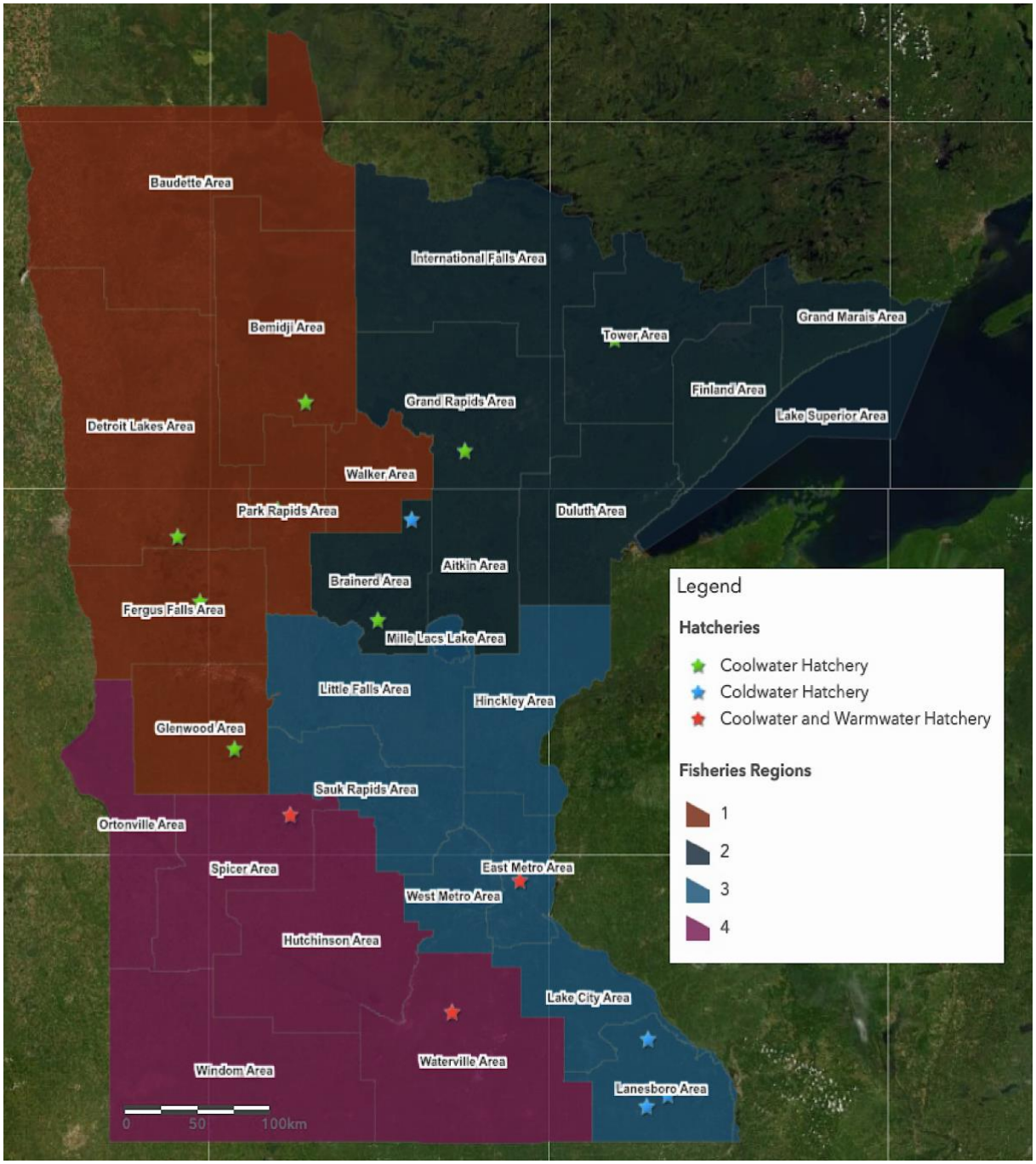

Figure 3. Map of Minnesota showing the boundaries of area fisheries offices and regions. An area fisheries office oversees the management and monitoring of lakes within their boundaries. Hatcheries are also shown, with cool and warmwater hatcheries being walleye hatcheries. Coldwater hatcheries are primarily for trout stocking. Map made using ArcGIS Online with data from MN Geospatial Commons.[34]

[34] Minnesota Geospatial Commons, "Minnesota Geospatial Commons," Minnesota DNR, https://gisdata.mn.gov/.

In terms of potential direct risks to ecosystems, walleye stocking must be done with respect to current walleye populations and other species' populations so as not to disrupt the food web of a lake.[35] Lake size, lake productivity, and angler pressure also must be considered.[36] Walleye supplementation must be implemented to keep walleye populations balanced with other fish species, and natural walleye populations must initially be low or under heavy angling pressure for stocking efforts to be necessary.

Walleye populations, like any other species in a natural setting, have a carrying capacity.[37] A carrying capacity entails the maximum population size for a species that its environment can support. The imposed stocking density, otherwise noted as pounds of fingerlings stocked per littoral acre, or area where lake productivity occurs, must be done in accordance to a lake's respective carrying capacity and is essential for maintaining an efficient and responsible fish stocking program.[38] At optimal stocking densities, a single stocked walleye that is harvested costs $5.84, based on statewide harvest numbers and funding.[39] Past optimal stocking density, which varies from lake to lake, the extra stocking effort could be ineffective, making the optimal stocking cost per walleye much higher. This would be an irresponsible use of funding that could be used for the stocking of other systems or towards other fisheries management efforts. Opposite to this is stocking at densities that are too low, comparative to the carrying capacity. Stocked walleye have a great chance, since stocked fingerlings range

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[35] Andrew H. Fayram, Michael J. Hansen, and Timothy J. Ehlinger, "Characterizing Changes in Maturity of Lakes Resulting from Supplementation of Walleye Populations," *Ecological Modelling* 197, no. 1/2 (2006): 104.
[36] Reed and Staples, "Evaluation of Two Different Stocking Rates of Small Walleye Fingerlings in Minnesota Lakes," 1243.
[37] Peter C. Jacobson and Charles S. Anderson, "Optimal Stocking Densities of Walleye Fingerlings in Minnesota Lakes," Ibid. 27, no. 2 (2007): 650.
[38] Ibid.
[39] Ibid.

anywhere between 45 and 220 millimeters (2 and 8 inches) in size, to be preyed upon by other predatory fish.[40] Since stocked walleye have a low recruitment rate, otherwise noted as being added to the population, stocking at too low of density would prove ineffective and would be an irresponsible use of fisheries management funds and effort.[41]

Besides stocking densities and their respective issues with effort and funding, there is also a risk for stocked walleye recruitment to increase and for walleye to outcompete other predators, which could also lead to increased pressure on smaller fish and invertebrates. Angler pressure could also decrease, leaving stocked and naturally occurring walleye to flourish without significant angler influence. Though angler effort and walleye populations on walleye fisheries are closely monitored, these are still potential problems.

Top-down effects can occur because of increased predation by a larger-than-usual walleye population. This means an imbalance in the food chain and a subsequent trophic cascade.[42] An example situation is that walleye, a predator, will reduce numbers of non-predatory fish, fewer non-predatory fish results in greater numbers of zooplankton, and a greater number of zooplankton results in less phytoplankton. This cascade can impact the lake's clarity and reduce lake productivity, or the amount of photosynthesis that happens in the system. Some organisms in the system may not be adapted to such conditions of water quality or clarity. Some might rely on lower clarity water to stay elusive. Some may lack a food source, depending on their trophic level. Imbalances in the trophic ladder can equal out with time due to food web

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[40] Jeffrey R. Reed and David F. Staples, "Evaluation of Two Different Stocking Rates of Small Walleye Fingerlings in Minnesota Lakes," Ibid.37, no. 6 (2017): 1243.
[41] Peter C. Jacobson and Charles S. Anderson, "Optimal Stocking Densities of Walleye Fingerlings in Minnesota Lakes," Ibid.27, no. 2 (2007): 650.
[42] Warwick F. Vincent, *Lakes: A Very Short Introduction* (New York, NY: Oxford University Press, 2018), 88.

interactions and are therefore not as much of an issue when it comes to walleye stocking. This does mean, however, that an over-abundance of walleye can cause a temporary shift in the trophic ladder that may harm phytoplankton and non-predatory fish populations, but ultimately will come back to equalize walleye populations. This would be an inefficient use of stocking funds and efforts and may cause temporary imbalances to certain populations and may temporarily change water clarity and quality.

In terms of the productivity of an aquatic system, walleye do best in mesotrophic systems.[43] On each end of the trophic spectrum, oligotrophic systems are clear water systems with little productivity and eutrophic systems have low clarity and significant productivity compared to other systems. Mesotrophic systems are a "happy medium" since they have moderate nutrient content, moderate clarity, and moderate aquatic vegetation. This allows for the most diverse lake system since some species are best suited for one system or the other.[44] Walleye can do well naturally in such systems since their prey does not do well in eutrophic systems and their tapetum lucidum, the light-sensitive membrane in their eye, allows them to see in waters with lower clarity. A problem comes into play if walleye populations increase since a trophic cascade would ensue, leading to walleye having less prey and being less competitive against other predators due to their light-sensitivity being less advantageous in oligotrophic systems. Walleye populations belonging to oligotrophic systems are known to be unstable, leading to further spending and efforts by fisheries managers if angler desire for walleye in that system exists.[45]

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[43] Bethke and Staples, "Changes in Relative Abundance of Several Minnesota Fishes from 1970 to 2013," 72.
[44] Vincent, *Lakes: A Very Short Introduction*, 74.
[45] Fayram, Hansen, and Ehlinger, "Characterizing Changes in Maturity of Lakes Resulting from Supplementation of Walleye Populations," 113.

Another potential problem with stocking is that genetic variability in a walleye fishery can decrease. Stocked walleye fry in a particular lake come from the same hatchery and angling pressure will reduce native walleye numbers, or the ones that are already in adulthood, at a greater rate than those that are stocked.[46] Angling pressure can lead to fewer reproductive opportunities, depending on the age of walleye that are taken and the rate at which walleye are harvested.[47] The fishery is then left with fewer native walleye able to reproduce and a new addition to the fishery that comes from the same hatchery. Less genetic variability in a lake's walleye population can happen because of this and may lead to a collapse of the fishery, though overfishing and environmental changes are also usually to blame for collapse.[48]

Stocking is the most widely adopted fisheries management strategy to keep walleye fisheries viable for anglers. The issues mentioned are possible, but stocking efforts by fisheries managers are closely monitored and have been safe and effective. In a majority of cases, stocking as a management strategy is done correctly. The problem with stocking, rather, is the subsequent pressure from anglers and the drive for fisheries managers to keep anglers happy. Fisheries managers then lead anglers to believe that their angling desires and respective management decisions are justified and non-problematic, reinforcing their belief in how fisheries should be managed.

There are several other management strategies that are more sustainable, require less funding, and allocate more efforts into the management of other species. However, with the current angling culture, walleye stocking must continue to keep up with the current angler

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[46] Brandon E. Allen et al., "Loss of Snp Genetic Diversity Following Population Collapse in a Recreational Walleye (Sander Vitreus) Fishery," *Canadian Journal of Fisheries & Aquatic Sciences* 75, no. 10 (2018): 1648.
[47] Ibid.
[48] Ibid.

interest and subsequent funding. The choices of fisheries managers, therefore, are potentially a political issue. Community relations with fisheries managers are kept in good health through maintaining populations of walleye large enough for anglers to exploit. Stocking walleye is the prime management strategy for producing the most walleye, but other strategies can produce higher quality walleye and remove the efforts required for stocking. These other management strategies can be implemented in walleye fisheries to allow natural reproduction and for walleye to reach peak size for anglers. These regulations include bag limits (how many walleye can be kept) or size-specific harvest/slot limit (walleye must be a certain length to be kept). These strategies, however, are not popular with anglers because they prevent anglers from taking many walleye and harvesting the size of the walleye they want. Implementing other strategies is a smart move for producing a sustainable and higher quality fishery but can result in backlash from anglers. It can also lead to anglers moving to another fishery where such regulations are not in effect, putting more pressure than usual on that system. "Five attributes addressing fishing regulations, being bag limit or slot limit, fishing quality (abundance or size), and travel time (distance from home) all affected lake choice when fishing for walleye."[49] If anglers can choose between walleye fisheries, they are likely to choose the one with fewest regulations and the best chance for catching many walleye.

There are implications for anglers being this concerned with catching many large walleyes and favoring stocking. These issues are indirect risks associated with walleye management. Stocking increases the likelihood for a fishery to be exploited by anglers, putting

[49] Carlin, Schroeder, and Fulton, "Site Choice among Minnesota Walleye Anglers: The Influence of Resource Conditions, Regulations and Catch Orientation on Lake Preference," 300.

pressure on the ecosystem.[50] The low awareness of anglers on their impacts, given their fishing habits, is also detrimental. Anglers that are concerned with catching many walleyes by means of stocking, more-so than catching few walleyes under other management strategies and protecting aquatic habitat, are found to be against ecological management.[51] In a survey of anglers by Schroeder et al. (2018), a majority of anglers have been found to have anti-habitat management attitudes, have a lower level of commitment to fishing, have less trust in fisheries agencies, and spend less time fishing in natural water bodies as compared to anglers with primary concern for aquatic ecosystem health.[52] This is detrimental, as it perpetuates a narrative amongst traditional anglers to see fisheries as a commodity and not an ecologically important entity. Anglers concerned with their catch over the health of aquatic ecosystems are likely to have a dissociation with the environment.[53]

Angler Exploitation

With walleye's high popularity amongst anglers, walleye fisheries are prone to be exploited. Stocking of walleye fisheries is likely to lead to exploitation, since there are more walleye and likely no added regulations to prevent anglers from catching the fish they want. Blackwell et al. cover the concept of exploitation well, explaining, "exploitation of walleye populations is known to result in substantial changes in population parameters, including changes in recruitment patterns, age at maturity and growth."[54] The pressure that anglers put on

[50] Blackwell, Kaufman, and Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," 59.
[51] Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," 666.
[52] Ibid.
[53] Ibid., 675.
[54] Blackwell, Kaufman, and Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," 60.

walleye fisheries can be substantial, and once anglers are not satisfied with the fishery or new regulations are put in place, anglers are likely to move and put pressure on a new system. “Not only can the fish population characteristics be altered once exploitation occurs, but angler behavior can also change. Spencer et al. (2002) suggested that anglers in remote northwestern Ontario could quickly overfish an unexploited walleye population upon gaining access to the fishery, but when yield declined, anglers would move to other unexploited populations.”[55] This cyclical action of anglers exploiting walleye fisheries obligates fisheries managers to impose management strategies, especially stocking, to keep fishery populations at stable levels.

Another issue that is complementary to angler exploitation is lake development. Lakes are generally developed for their aesthetic value, as well as their value as a recreational resource. A fishery open to anglers is a key component for a lake’s development. Having a walleye fishery can ultimately lead to the building of homes, establishment of fishing resorts, channeling of lake beds, and the addition of boat landings. All of these are likely to increase angling pressure and harm the shoreline habitat of a lake. Environmental stressors like substrate manipulation and aquatic vegetation removal ruin spawning habitat and land-use changes increase the likelihood of erosion and runoff.” Lakeshore development, increases in cultivated area, and urbanization near lakes all result in increased nutrient loading in lakes and have altered hydrological processes.”[56]

In addition to land-use changes and the development of lakes, there are other ways that the current angling culture and other anthropogenic activity put negative pressure on aquatic systems. Waters that are exposed to pollutants that pose potential harm to human use of the water

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[55] Ibid.
[56] Bethke and Staples, "Changes in Relative Abundance of Several Minnesota Fishes from 1970 to 2013," 69.

or the aquatic community are classified as impaired.[57] As of 2020, there were 2051 lakes classified as impaired in Minnesota.[58] The loading of nutrients due to agriculture, lake development, and land-use changes can make systems eutrophic, limiting dissolved oxygen in the system and a bloom of phytoplankton and algae.[59] Phosphorus and nitrogen used in agricultural or lawn settings, as fertilizer, can boost the production of algae and phytoplankton.[60] Runoff of salts and sediments can also increase water salinity and reduce water clarity. These can change the biotic community drastically, reducing populations of species of aquatic invertebrates and pollution-intolerant fish that are not adaptable to such changes.

Angler Dependence

There are several potential issues with walleye dependence. Many anglers depend on walleye as a food source for their intake of EPA and DHA, otherwise known as omega-3s, and because their filets are larger and better tasting than other fish.[61] However, in a study of freshwater fish by Strandberg et al., walleye were found to have lower EPA and DHA levels compared to other freshwater species.[62] Not only are their EPA and DHA levels comparatively lower, but walleye mercury levels are comparatively higher as well (Table 2). These levels are elevated the larger the walleye is due to bioaccumulation and biomagnification of mercury up the food chain.[63] Atmospheric deposition is another issue that affects aquatic systems and continues to do so. Higher atmospheric CO_2 results in increased dissolved CO_2 in lakes. Atmospheric

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[57] Minnesota Pollution Control Agency, "Draft 2020 Impaired Waters List," ed. Minnesota PCA (2020).
[58] Ibid.
[59] Vincent, *Lakes: A Very Short Introduction*, 114-15.
[60] Ibid.
[61] Ursula Strandberg et al., "Spatial and Length-Dependent Variation of the Risks and Benefits of Consuming Walleye (Sander Vitreus)," *Environment International* 112 (2018): 252.
[62] Ibid., 256.
[63] Ibid., 255.

deposition of mercury is also an issue: "99.5% of mercury found in fish tissue is from the atmosphere and 70% of that mercury is from anthropogenic sources."[64] Atmospheric mercury eventually finds its way into lakes, accumulating in the tissues of larger fish like walleye.[65]

Table 2. Mean EPA + DHA (mg 100 g^{-1}) and mercury (µg g^{-1}) contents in the muscle of common freshwater fish from North America (the northern USA and Canada). Data were taken from Strandberg et al. (2018).[66] Species assigned a score (1 through 17) based on both their EPA + DHA and mercury content. Higher EPA + DHA received a higher score, while higher mercury got a lower score. These values were added to award a composite score, with a higher score reflecting an overall "better" fish in terms of dietary value and mercury risk. Walleye are highlighted in red, ranking 14 out of the 17 species Strandberg et al. studied based on these factors.

Species	EPA + DHA (mg 100 g_{-1})	Mercury (µg g_{-1})	Composite Score
Lake Whitefish	653	0.09	30
Rainbow Trout	516	0.11	25
Cisco	569	0.14	24
White Crappie	109	0.08	20
Pumpkinseed	128	0.09	20
Brown Trout	365	0.17	20
Lake Trout	741	0.41	19
Yellow Perch	144	0.14	18
Bluegill	94	0.08	18
Black Crappie	111	0.11	16
Largemouth Bass	154	0.29	16
Brown Bullhead	101	0.10	16
Smallmouth Bass	145	0.33	14
Walleye	193	0.84	13
Channel Catfish	128	0.20	13
Northern Pike	137	0.38	11
Common Carp	59	0.17	8

Other fish species would be much better choices for anglers if they were looking to satisfy their EPA and DHA intake without the risk of higher mercury levels found in walleye.

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64 Minnesota Pollution Control Agency, "Statewide Mercury Reduction Plan," ed. Minnesota PCA (2009).
65 Strandberg et al., "Spatial and Length-Dependent Variation of the Risks and Benefits of Consuming Walleye (Sander Vitreus)," 255.
66 Ibid., 258.

An adequate daily intake of EPA + DHA is 250 mg.[67] Intake of walleye is likely high amongst serious anglers, so mixing in or switching entirely to another species would be ideal for anglers looking to satisfy their EPA and DHA intake through eating self-caught fish.

Some common game species include crappies, bluegill, pumpkinseed, and yellow perch, with some more uncommon game species being cisco, whitefish, and the trout and salmon species. Non-game species listed that can supply adequate EPA and DHA are bullheads and catfishes. Some sucker species, though not listed, are also a popular choice amongst anglers. These non-game species are typically not favored. Many common species can make great alternatives for anglers in terms of nutritional benefit and angling motivations.

Non-game species are not typically desired by anglers due to their taste or because of the appearance of the fish.[68] The association of these fish with being "gross" or "garbage" has led to these fish having "untapped potential" for the use of anglers. This association has also led to negative bias against this species and a misunderstanding of them within the angling community.[69] Some of these species are great tasting and are nutritionally beneficial, making a great substitute for eating typical game species. Some of these species can also put up great fights and make great fishing experiences.[70] Either way, non-game species have utility for anglers looking to satisfy their angling motivation. There are species that anglers can catch if they are fishing for something big, wanting to catch many fish, or if they are looking to catch something to eat. Non-game species can be assigned to specific niche angling motivations to

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[67] Ibid., 253.
[68] Jake VanDeLaare, "'Trash Fish' Don't Deserve Such a Bad Reputation," *wideopenspaces*, 2018.
[69] Ibid.
[70] Ibid.

reduce walleye angling pressure and increase angler knowledge of non-game species, all while providing benefits of outdoor experiences to anglers.

Another issue with angler dependence on walleye is the lack of knowledge amongst anglers regarding other species. The current angling culture is particularly interested in certain species of fish, which have been defined as "game species". These species received their commonly agreed-upon status from anglers due to their perceived value. This can be problematic since it prioritizes the treatment, management, and awareness of game species over other species that have importance to the biotic integrity of an aquatic system. As previously mentioned, anglers typically take several factors into play when it comes to angling orientation. Non-game species do not necessarily fit these factors since traditional anglers do not have the equipment or education to understand these species as well as game species. Since anglers are particularly interested in a species' utility, as a food source especially, non-game species are categorized as such due to angler assignment. Even though many non-game species are palatable and in greater abundance than game species, angler bias has developed to a point where the views of non-game species have become problematic. Past experiences, social norms, and cultural biases have built walleye up to be the most favorable species amongst anglers and have made anglers collectively disregard non-game species.[71]

Walleye prioritization has arguably clouded the minds of anglers. Their attachment to the lake system they fish on and the environment, in general, is reflective of their angling motivations;

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[71] Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," 674.

> Findings suggest that anglers with higher catch orientations generally place greater importance on fishing-related experience outcomes, while anglers with a lower catch orientation emphasize more general experience. Kyle and colleagues (2007) found that anglers who were least concerned with catching and consuming fish expressed the strongest social motivations and attachment to the lake system being studied, while anglers who were most concerned with catching large fish were least motivated by non-angling factors (i.e., escape, privacy, family, social) and had a comparatively low attachment to the lake system.[72]

Anglers differ in their motivations, but anglers concerned primarily with their fishing outcome are likely to be disconnected from the natural world and their impact on it.

Lack of awareness of other species and aquatic systems as a whole is a result of angler prioritization of walleye and other game species. Fisheries management resources are dedicated to walleye hatcheries and stocking efforts to meet angler demand. There are efforts to manage and protect other species that are crucial to the health of aquatic systems but are not seen as important in the eyes of anglers.[73] There are implications with anglers lacking the knowledge and awareness of non-game species and how game fishing can be unsustainable or implicative to aquatic systems in terms of pressure.

Climatic changes are another human-caused threat for aquatic systems. Since 1895, there has been a 3° F (1.67° C) increase in state-wide average temperature, leading to a rise in average water temperatures (Figure 5).[74] Shorter durations of ice cover on Minnesota lakes have been linked to the warmer and more variable climate.[75] Ice-out data taken since 1990 on 13 Minnesota

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[72] Schroeder and Fulton, "Comparing Catch Orientation among Minnesota Walleye, Northern Pike, and Bass Anglers," 356.
[73] Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," 674.
[74] Minnesota Department of Natural Resources, "Past Climate Data for Minnesota," (St. Paul, MN: Minnesota DNR, 2020).
[75] Bethke and Staples, "Changes in Relative Abundance of Several Minnesota Fishes from 1970 to 2013," 69.

lakes across the state shows a trend of earlier ice-out each year.[76] Members of the biotic community will be forced to adapt to the increasing water temperature. Earlier ice-out dates can also influence fish spawning to start too early or too late, especially if year-to-year ice-out dates are variable. This could especially pose a threat to walleye recruitment, requiring additional stocking and management.

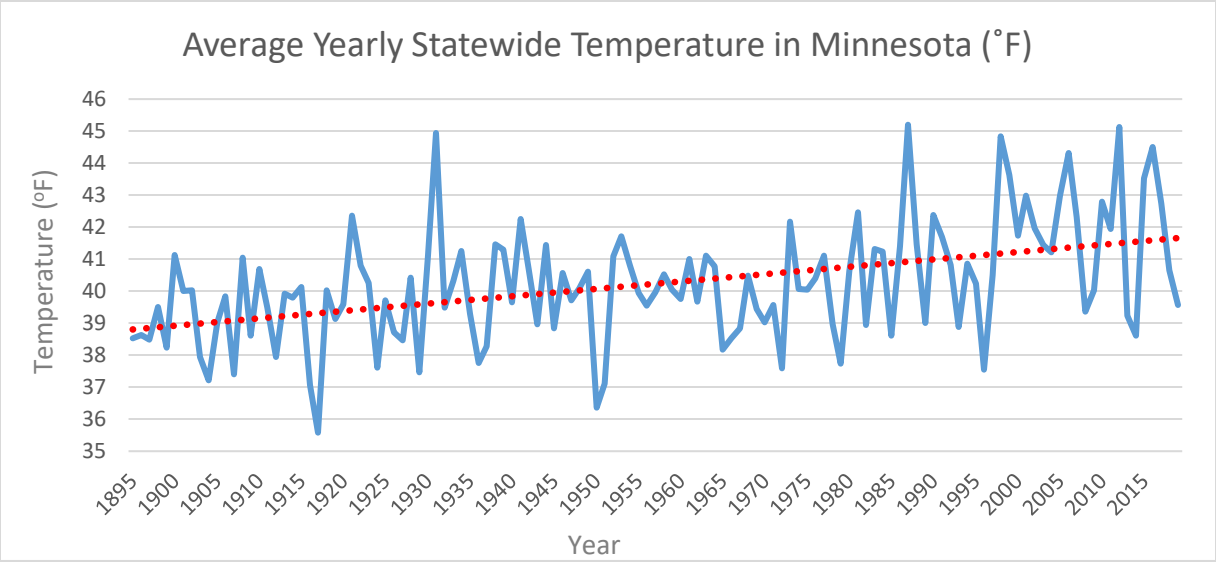

Figure 5. The average annual statewide temperature in Minnesota. Average temperatures are shown in degrees Fahrenheit (ºF) for each year from 1895 to 2019. The red line shows the trend in average temperature rise over the entire time period. Warming has occurred at a rate of 0.023 degrees (ºF) per year. Data were taken from "Past Climate Data for Minnesota" from the Minnesota Department of Natural Resources (2020).

Mille Lacs Lake: A Case Study

Mille Lacs Lake is perhaps the greatest example of angler exploitation and dependence on walleye in Minnesota. The angling culture's presence here highlights the display of angler attitudes towards walleye fishing and their views on and trust in fisheries agencies. Mille Lacs Lake is located in central Minnesota and covers 207 square miles (mi^2), making it Minnesota's second-largest inland lake (Figure 6).[77] The lake is unique in that it is relatively shallow, not

[76] Brian Stensaas, "A Closer Look at Historical Ice-out Dates around Minnesota," *StarTribune* 2016.
[77] Minnesota Department of Natural Resources, "Mille Lacs Lake," https://www.dnr.state.mn.us/millelacslake/index.html.

exceeding 42 feet in depth[78]. It is also unique in that, due to its shallow uniformity, Mille Lacs Lake does not possess a thermocline.[79] The thermocline, in limnology, is the boundary where there is a sharp drop in water temperature and a decline in oxygen.[80] The thermocline is at a specific depth that may change throughout the year and is influenced by the lake's morphology and several environmental factors. Since Mille Lacs Lake lacks a thermocline, it is a prime lake for walleye. Walleye have sufficient oxygen and can forage throughout the lake with the absence of the thermocline, maximizing the area in which they can live and the number of fish that can live in the lake.[81] It is no surprise that anglers find this lake to be the perfect fishery

Figure 6. Mille Lacs Lake. "Lake Mille Lacs - Minnesota" by Doug Kerr is licensed under CC BY-SA 2.0

78 "Lakes, Rivers, and Wetlands Facts," Minnesota DNR, https://www.dnr.state.mn.us/faq/mnfacts/water.html.
79 Explore Minnesota, "Lake Mille Lacs," https://millelacs.com/lake/.
80 Vincent, *Lakes: A Very Short Introduction*, 36.
81 Minnesota Department of Natural Resources, "Mille Lacs Lake," Minnesota DNR, https://www.dnr.state.mn.us/millelacslake/index.html.

for their fishing excursions. The size of the lake and the abundance of walleye have brought thousands of anglers to Mille Lacs lake for fishing opportunities over the years, with the subsequent arrival of other interests like bait and sporting goods shops, resorts, fishing guides and charters, and the building of homes and other real estate. There are currently 20 fishing resorts or campgrounds on Mille Lacs Lake.[82] The lake was the epitome of what walleye angling can do for the economy. People from all over were coming to get their share of fish or were taking the opportunity to benefit from the demand. Mille Lacs Lake soon turned from a pristine fishery into a commodity.

Though the walleye fishery in Mille Lacs Lake has thrived for most of its years as a popular fishery, the effects of walleye exploitation were not necessarily apparent to anglers until 2013 when the Minnesota Department of Natural Resources changed walleye fishing regulations.[83] Slot limits, or size guidelines for walleye harvest, were established on Mille Lacs Lake starting in 1999 in an effort to stabilize the walleye population, but these measures were ineffective over the years.[84] The fishery, as fisheries biologists have said, has reached a "precarious point."[85] The walleye population can rebound, but only anglers and fisheries managers take the right precautions and if regulations are improved. Years of angling pressure and lakeshore development has slowly changed walleye populations and the lake itself. Tribal rights to the walleye fishery, set in the 1837 Treaty of St. Peters, also added to the harvest

[82] Minnesota Resorts Directory, "Lake Mille Lacs Resorts," Minnesota Resorts Directory, https://minnesotaresortsdirectory.com/lake-mille-lacs-resorts/.
[83] Matthew Steffes, "Implications for the Mille Lacs Lake Fishery with Continued Enforcement of the 1837 Treaty of St. Peters," *Hamline University's School of Law's Journal of Public Law and Policy* 35, no. 2 (2014): 383.
[84] Ibid., 383-84.
[85] Dave Orrick, "How Many Walleyes Die after Being Released? New Mille Lacs Study Probes 'Hooking Mortality'," *Pioneer Press*, 2016-05-27 2016.

pressure on the fishery.[86] Anglers, both Minnesota citizens and tribal members, have to follow regulations set by the state. The new window of size that a walleye had to be in order to be harvested was between 18 and 20 inches, but an angler could harvest one walleye greater than 28 inches.[87] This was an effort by the Minnesota DNR to bring back the lake's abundant walleye population that had been declining in previous decades. Other historically popular walleye fisheries in Minnesota, specifically, Upper Red Lake, have been subject to overfishing and environmental changes that have resulted in lower walleye abundance.[88] These lakes and their fisheries are not as successful as they once were, therefore the Minnesota DNR is taking precautionary steps to protect the Mille Lacs walleye due to an observed decline in walleye abundance. Regardless of the motives behind their decision, angler interests did not agree with the new regulations and the decision was met with much controversy. The economy of the area was hit hard, and it was argued that tribal sovereignty was being violated.[89] However, there is justification for why this move by fisheries managers was a fair decision and why this case study suggests the angling culture centered on walleye needs to change.

Mille Lacs Lake has historically been a walleye haven due to favorable hydrological factors. One important factor is that the lake has historically been eutrophic. This is a plus for walleye since they can live in such conditions and can compete well in such water clarity due to their eyesight. However, with increased angling pressure and lake development, water clarity has

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[86] Steffes, "Implications for the Mille Lacs Lake Fishery with Continued Enforcement of the 1837 Treaty of St. Peters," 376.
[87] Ibid.
[88] R. Scott Gangl and Donald L. Pereira, "Biological Performance Indicators for Evaluating Exploitation of Minnesota's Large-Lake Walleye Fisheries," *North American Journal of Fisheries Management* 23, no. 4 (2003): 1309.
[89] Steffes, "Implications for the Mille Lacs Lake Fishery with Continued Enforcement of the 1837 Treaty of St. Peters," 396.

improved. Along with this, climatic changes in Minnesota have made Mille Lacs warmer, which is not ideal for walleye which prefer colder water temperatures.[90] The reduction of phosphorus sounds like a benefit from a water quality and water clarity point-of-view, but the fish community of Mille Lacs is structured to thrive in a eutrophic system.

The significant development that exists around the lake, of course, requires septic systems due to a large number of anglers, tourists, businesses, and residents being present. Older systems were known to allow nutrients, particularly phosphorus, to seep from these septic systems into the lake.[91] These have been improved to stop point-source pollution from entering Mille Lacs Lake. The improvement to these systems explains the sharp reduction of phosphorus in Mille Lacs that was noticed in 1990.[92] This reduction in phosphorus subsequently reduced algae and phytoplankton numbers, improving Mille Lacs' water clarity. This is a plus for water quality, but not so much the ecological community. In addition to the reduction of phosphorus, not much later the lake was also the new home of an aquatic invasive species.

A human-caused water impairment that is becoming an ever-significant threat is invasive species. "Introductions of exotic plant species like curly-leaf pondweed (*Potamogeton crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*), zebra mussels (*Dreissena polymorpha*), and aquatic invertebrates like spiny waterflea (*Bythotrephes longimanus*) and rusty crayfish (*Orconectes rusticus)* have reduced indigenous diversity in the native plant, mussel, and invertebrate communities."[93] These species reduce populations of native vegetation and

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90 Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'."; Orrick, "How Many Walleyes Die after Being Released? New Mille Lacs Study Probes 'Hooking Mortality'."
91 Tribune Content Agency, "Deep Dive on Mille Lacs Lake Emphasizes Downside of Water Clarity for Certain Fish," *SC Times* 2019.
92 Ibid.
93 Bethke and Staples, "Changes in Relative Abundance of Several Minnesota Fishes from 1970 to 2013," 69.

invertebrates, disrupt the cycle and allocation of nutrients, and change the quality of water and the availability of food for walleye, making it harder for them to play their role as a top predator. The pressure walleye anglers put on aquatic systems and their willingness to move to new walleye fisheries to exploit fish increases the likelihood for invasive species to spread and damage other aquatic systems.

Zebra mussels entered Mille Lacs in 2005, further clearing the water of phytoplankton.[94] These mussels quickly reproduce and congregate in thick masses, filtering out phytoplankton and small particles in the water (Figure 7).[95] Zebra mussels made their way into Mille Lacs due to high angling traffic. All it takes is for a boater to enter their uncleaned boat, trailer, or equipment into a clean lake to unintentionally bring the aquatic invaders from an infested lake to a new one.

This has been the case with many other popular lakes. Thankfully, guidelines and cleaning protocols are stricter today to prevent the spread of aquatic invasive species. However, Mille Lacs is a prime example of what they can do to a fishery. In Mille Lacs, walleye are not able to compete as well as other fish due to zebra mussels making the water oligotrophic.

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[94] Tribune Content Agency, "Deep Dive on Mille Lacs Lake Emphasizes Downside of Water Clarity for Certain Fish."

[95] Minnesota Department of Natural Resources, "Zebra Mussel (Dreissena Polymorpha)," Minnesota DNR, https://www.dnr.state.mn.us/invasives/aquaticanimals/zebramussel/index.html.

Figure 7. Zebra mussels (*Dreissena polymorpha*) congregated on a native clam. "Native Great Lakes Unionid Mussel encrusted with Zebra Mussels" by NOAA Great Lakes Environmental Research Laboratory is licensed under CC BY-SA 2.0.

The water clarity on Mille Lacs peaked in 2013, varying depending year-to-year on rainfall, sunlight, and algae growth.[96] Water clarity improvement has been the case on many other lakes with zebra mussels and the reduction of point-source pollution. It has also been the case that these improvements have not significantly hurt walleye populations on other lakes, which is surprising since walleye depend on lower water clarity and dark spaces.[97] In the lakes where water clarity has improved, walleye can still thrive in deeper water where it is darker.[98] The Mille Lacs walleye, however, are not able to do so. The lake, being uniform in depth and being relatively shallow, has prevented walleye from thriving like they usually do. Thus, the walleye fishery in Mille Lacs has slowly become a system that walleye are not adapted to.

There will still be walleye in Mille Lacs, just not in the abundances that are historically thought of. The lake system is changing as all systems eventually do. Fisheries change over time

[96] Tribune Content Agency, "Deep Dive on Mille Lacs Lake Emphasizes Downside of Water Clarity for Certain Fish."
[97] Ibid.
[98] Ibid.

due to ecological changes, anthropogenic influences, and climatic changes. In this case, heavy angling, warmer water, invasive species, and water clarity changes are the reasons for a declining walleye population. Even with the decline in abundance due to water clarity improvements, walleye anglers and others that depend on walleye to make capital such as resort owners and fishing guides disagreed with the Minnesota DNR's findings and are doubtful of the claim that the lake cannot support the walleye that they depend on and desire. If fisheries managers are trying to protect a natural resource for anglers to sustainably use, then why are people angry with them?

Anglers are still allowed to catch walleye under new fishing regulations and, depending on the specific regulations of the fishing season, they can sometimes keep them. The lower allowed harvest of walleye does not necessarily mean slower walleye fishing; anglers can still find success in targeting walleye on the lake.[99] Some year-to-year regulations do not allow the harvest or targeting of walleye for the season depending on fisheries reports, but that does not mean anglers cannot find fishing opportunities on the lake.[100] Populations of game fish like smallmouth and largemouth bass, northern pike, muskellunge, yellow perch, black crappie, and cisco are all available for anglers, acknowledging their respective regulations.[101] These all can provide adequate angling experience and funding for resorts, fishing guides, and other industries around Mille Lacs. The angling community involved, however, is not a fan of such prioritization of other species. These other species in Mille Lacs could easily be promoted over walleye, as some resorts and guides are doing to boost business and angler involvement on the lake, but the

[99] Minnesota Department of Natural Resources, "2016 Mille Lacs Regulations Designed to Keep Walleye Fishing Open - Outdoornews," *Outdoor News*, 2016-03-21 2016.
[100] Ibid.
[101] "Lakefinder."

angling community, in general, is not willing to accept the changes to walleye populations nor target other species over walleye.[102]

In 2015, the Minnesota DNR approved the addition of a walleye hatchery on Mille Lacs to help the population recover.[103] The $3.5 million project was supported by anglers and resort owners alike, but agency biologists warned that a hatchery and stocking efforts likely will not help rebuild the historic population.[104] Walleye fry, in a time where walleye abundances are at a 30-year low, are not able to reach maturity due to being eaten by other predatory fish and having a lack of food.[105] Due to water clarity changes and lower competition from adult walleye, other predatory fish like basses and northern pike are in greater abundance. Aquatic invasive species like zebra mussels and spiny waterflea have disrupted the food chain of Mille Lacs, reducing available food for walleye fry by as much as 50%.[106] Due to these factors, reviving the once abundant walleye population on Mille Lacs Lake may not be possible with stocking alone. The incentivizing of other species and the enforcement of the new slot limit regulations are currently the best option. However, anglers still flock to Mille Lacs in the summer to get their bag limit of walleye if there is one at all for a particular season. The pressure on the walleye population, even with the regulations slowing down harvest, may still be detrimental to walleye.

Catch-and-release is a prevalent method on Mille Lacs, depending on the year and the respective regulations. Anglers will make attempts to catch walleye that fall within the year's allowed slot limit for harvest. If they are not legal for harvest, they must be returned to the lake.

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102 Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'." *MPR News* 2018.
103 Forum News Service, "Dnr Will Add Fisheries Staff and Hatchery Facility at Mille Lacs," *Fergus Falls Journal* 2015.
104 Kraker, "Why Walleye Is Minnesota's 'Holy Grail of Fish'," *MPR News* 2018.
105 Forum News Service, "Dnr Will Add Fisheries Staff and Hatchery Facility at Mille Lacs."
106 Tribune Content Agency, "Deep Dive on Mille Lacs Lake Emphasizes Downside of Water Clarity for Certain Fish."

When anglers cannot harvest walleye in a season, they may not be targeted. Targeting entails fishing specifically to catch walleye or fishing with live bait that walleye prefer.[107] Anglers most likely will make repeated catches before reeling in a legal walleye for harvest. The increased number of walleye being caught and released poses a question for fisheries managers. During the years where walleye angling is allowed but restricted on Mille Lacs, is the effect anglers have on walleye worse than with no restrictions? Catch-and-release angling as a management technique can be a great management technique for keeping fish in the lake and allowing anglers to still catch them, but there is a risk of mortality to the fish in question.

The Minnesota DNR estimates how many walleye die in Mille Lacs from being caught and released by anglers by considering multiple factors.[108] The Minnesota DNR found that warmer water, especially when water temperatures got above 70$_{o}$ F (21$_{o}$ C), increased the likelihood of hooking mortality.[109] With a trend of climatic warming, this may become an even bigger concern for walleye angling in the summer months. Walleye caught in deeper water were also more likely to die[110], since the depressurization associated with being quickly brought to the surface can make the air bladder, a buoyancy-control organ in walleye, expand.[111] Smaller walleye and large walleye were also more likely to die from being caught and released.[112] With the slot limit window being in the medium-size range, the smaller and larger fish that must be

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[107] Minnesota Department of Natural Resources, "Minnesota Fishing Regulations," Minnesota DNR, https://www.dnr.state.mn.us/fishing/regs.html.
[108] Orrick, "How Many Walleyes Die after Being Released? New Mille Lacs Study Probes 'Hooking Mortality'."
[109] Ibid.
[110] Keith A. Reeves and Richard E. Bruesewitz, "Factors Influencing the Hooking Mortality of Walleyes Caught by Recreational Anglers on Mille Lacs, Minnesota," *North American Journal of Fisheries Management* 27, no. 2 (2007): 446.
[111] Ibid., 449.
[112] Orrick, "How Many Walleyes Die after Being Released? New Mille Lacs Study Probes 'Hooking Mortality'."

released have a worse chance of survival. Fish length, hook type, and angler handling were also important factors to consider since these dictated how deeply hooked a walleye was, whether the walleye bled, and how carefully the hook was removed from the walleye, and how gently the walleye was handled and returned to the water.[113]

To summarize, the ecosystem of the lake is changing, with walleye currently not being as viable as they once were. The fisheries agency that oversees Mille Lacs Lake, the Minnesota DNR, has been diligently monitoring and managing the lake's walleye population in hopes of pleasing anglers. The future for Mille Lacs as a popular walleye fishery, looking back at recent years' walleye abundances, looks bleak. Anglers and business owners alike deny that this is the end and continue to approve of and fund fisheries management efforts to increase walleye numbers, even though there is a consensus amongst them that the new regulations are unfair. The massive amount of capital that is attributed to walleye angling on Mille Lacs does not need to vanish because walleye are not abundant anymore. Mille Lacs Lake should be the prime example of a lake that has gone under ecological changes over time and is still a viable fishery. Walleye populations are not what they used to be, but that does not mean that anglers cannot utilize the lake for other fishing opportunities or other outdoor recreation. The situation around this lake is also a prime example of the angling culture's dependence on walleye and inattentiveness to ecosystem health and the "anti-walleye" suggestions of fisheries managers.

The Future of Angling

Currently, angling is one of the most popular forms of outdoor recreation in Minnesota. With the current estimate of anglers that target walleye the most being 70%, and with nearly 1.5

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113 Reeves and Bruesewitz, "Factors Influencing the Hooking Mortality of Walleyes Caught by Recreational Anglers on Mille Lacs, Minnesota," 449.

million licensed anglers in the state, walleye fishing is significant to the angling culture of Minnesota. The prioritization of walleye has potential implications and anglers have distanced themselves from the truth about their potential impact on aquatic systems. The future of angling participation looks promising, with increased participation to be likely due to more outdoor education, access, and exposure. With this increased pressure from anglers and the addition of threats like climate change and aquatic invasive species, assuming that the angling culture holds its course, walleye angling as it is will no longer be feasible. Freshwater ecosystems are subject to multiple stressors that have uncertain long-term impacts, many of which may be irreversible.[114] The norms of traditional angling will need to adjust to support the biotic integrity of aquatic ecosystems ahead of the desires of anglers. Only then will fishing be an option for outdoor recreation.

Solutions

There are several areas where change can occur and is possible. These changes can either be executed to change the angling culture to better prioritize aquatic systems or to help anglers adapt to changes that may be seen in the future. The integrity of aquatic systems should be the top priority, but to best complement both angling interests and the health of aquatic ecosystems, solutions should allow anglers to still be involved in their sport while concurrently restoring and monitoring aquatic ecosystems.

Fisheries Management Strategies & Angling Methods

Perhaps the simplest solution, in terms of implementation, is to change the strategies in which fisheries managers regulate and manage lakes. This means limiting angler influence on

[114] Emily M. Stewart et al., "Assessing Environmental Stressors on a Commercial Walleye Fishery from a Large Northern Ecosystem (Tathlina Lake) Using Water Chemistry and Paleolimnology," *Journal of Great Lakes Research* 42, no. 2 (2016).

populations through means of fishing regulations and sustainable management techniques, apart from stocking, that are low-cost and effort. These can limit the amount of walleye harvested while allowing effort and funding allocated towards stocking programs to be invested into habitat restoration and angler education programs. These strategies would still allow anglers to fish but would reduce the harvest of walleye or other regulated species. Many of these regulations and strategies are implemented already on certain lakes and are great options for rehabilitating fish populations without risking the ecological and genetic integrity of fish communities that stocking might.[115] Though these are effective management tools, the issue with having these only on certain lakes is that regulations will redirect serious anglers to put pressure on other systems where regulations will not interfere with their angling interests.[116] The current implementation of these strategies are effective on their respective lakes are effective, but are possibly counterproductive if not used state-wide.

The potential strategies and regulations that can be used include bag limits, slot limits or size-selective harvest, or special tags or stamps. A bag limit is a general regulation that defines the maximum number of fish that can be harvested by an angler. In Minnesota, it has been most commonly seen as an effective and widely-used strategy for restoring healthy sunfish populations that were historically overfished, particularly bluegill populations.[117] This has also been an effective tool to prevent the overfishing of walleye. During walleye's 10-month fishing season, there is currently a state-wide possession limit of 6 walleye, not having one walleye over

[115] Peter C. Jacobson and Charles S. Anderson, "Optimal Stocking Densities of Walleye Fingerlings in Minnesota Lakes," *North American Journal of Fisheries Management* 27, no. 2 (2007): 657.
[116] Blackwell, Kaufman, and Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," 63.
[117] Minnesota Department of Natural Resources, "Minnesota Fishing Regulations," (2020), 4.

20 inches.[118] The added size limit prevents overfishing of mature walleye, allowing for walleye to grow larger in an effort to encourage reproduction and angler success. Even with this general regulation, angling pressure is still high. Decreasing the general possession limit to a four-fish or a two-fish bag limit would help develop healthy fisheries and reduce angler pressure. The problem with the current management system is that lakes with stricter walleye regulations like a certain length requirement or bag limit that is less than six will direct anglers to other lakes with the general six-fish limit, increasing the harvest rate on lakes with fewer regulations due to demand.[119] This ultimately would be ineffective in improving the quality of walleye fisheries unless bag limits are reduced state-wide. The current six-fish limit has been effective, but stricter limits on some walleye fisheries apply stronger pressure on less-regulated lakes.

Slot limits, or size-selective harvest, is another related regulatory management strategy. The single 20-inch or larger regulation is an example of this, and some lakes even have a "length window" for which walleye can be harvested. These particularly help with producing quality walleye fisheries that will please future anglers. Although these are great strategies for the management of walleye, they are not significantly effective compared to bag limits unless the slot limit varies from lake-to-lake.[120]

> Special tags or stamps are another possibility to reduce angling pressure while also adding extra funding to aquatic management efforts. These would be supplementary to a fishing license if an angler wanted to legally harvest walleye. Trout in Minnesota, for example, are a species that require a special stamp to be legally harvested. This reduces the number of anglers putting pressure on these populations and aids in funding management and stocking efforts of these species.[121]

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[118] Ibid., 22.
[119] Carlin, Schroeder, and Fulton, "Site Choice among Minnesota Walleye Anglers: The Influence of Resource Conditions, Regulations and Catch Orientation on Lake Preference," 309.
[120] Ibid.
[121] Minnesota Department of Natural Resources, "Minnesota Fishing Regulations."

Although it is not required for anglers to legally harvest walleye, there already is an existing walleye stamp that anglers can purchase to fund stocking efforts.[122] Requiring the stamp for anglers to legally harvest walleye could be an option for fisheries agencies. This would reduce the number of walleye anglers that do not purchase the stamp and the funding could further support stocking and management of walleye and other species.

Catch-and-release angling is another strategy that can be implemented to reduce the pressure on walleye populations. This would be implemented to temporarily stop the harvest of walleye. Example situations could be times of walleye spawning, when bag or slot limits are not enough to rehabilitate populations, or when angling pressure is too high. Walleye season is closed from March through early-May to promote natural reproduction.[123] This could also be implemented for certain age groups or anglers without a walleye stamp. Age groups could mean implementing catch-and-release angling for certain groups of anglers, based on which age demographic takes the most walleye. This would allow seniors or adolescents, perhaps, to keep walleye versus anyone in-between that must catch-and-release. The walleye stamp, as it currently is, is not required for catching walleye but instead helps fund stocking efforts. Another walleye stamp or repurposing of the current stamp could be implemented, requiring anglers to purchase one to keep walleye. This could help reduce angling pressure on walleye while further funding walleye management. Those without a stamp would then only be allowed to catch-and-release walleye. Catch-and-release is a fairly simple management strategy, as it comes down to angler practice. This method of management can allow anglers to still enjoy the sport of fishing and is

[122] Ibid.
[123] Ibid.

an effective strategy, however, it must be done correctly by anglers since improper handling of fish can increase mortality rates.[124]

These strategies are suggestions. If all used collectively and in moderation, walleye stocking can continue and anglers could still enjoy catching quality walleye. The number of walleye that anglers can keep may be smaller, but these regulatory strategies can leave more quality walleye for other anglers while reducing pressure on aquatic ecosystems and supporting the funding of sustainable fisheries management.

Culture Change

Perhaps the most significant and promising change will need to occur at the angler level. The culture of angling in Minnesota has been accustomed to walleye and other game species, with particular focus on satisfying angler interest. Proctoring the angling culture change will be difficult since the culture and traditions of anglers are embedded.[125] Walleye anglers grew up knowing, catching, and appreciating walleye. Fisheries managers and other organizations have little control over angler education level and their fishing motivations.[126] Culture cannot change without first changing the norms and shared knowledge of walleye angling. The systematic development of what anglers believe to be most important has created the modern angling culture and has altered the beliefs of anglers in terms of what they see to be best for the lake ecosystem and themselves.

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[124] Reeves and Bruesewitz, "Factors Influencing the Hooking Mortality of Walleyes Caught by Recreational Anglers on Mille Lacs, Minnesota," 450.
[125] Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," 675.
[126] Ibid.

Culture change is possible, but it will not happen overnight. Angling culture is shared amongst anglers and is passed down through generations. The social norms that have built the angling community will be difficult to break away from since they are essentially expectations for anglers in terms of what they should be fishing for. Breaking social norms may seem blasphemous to other anglers and the opportunities and specialized gear for catching other species may not be as available as those for walleye. Culture change will take meticulous planning, time, and proper execution to educate the angling community on why the current model that is collectively agreed upon must change. Educational opportunities can be great pathways to changing angler beliefs. Culture change can happen through angler education opportunities, incentivizing other species, and fisheries management intervention.

Angler Education

The most important and promising method to change the angling culture is implementing angler education. There is a common dissociation between anglers and the environment. A majority of the angling populous is oblivious to the potential impact of angling pressure and fisheries manipulation. The angling culture has also been seen to exhibit a preference for fish stocking and open fisheries rather than having habitat management be prioritized.[127] Fisheries managers do not have an effective strategy to convince anglers that stocking and leaving fisheries open to exploitation are the only methods. Angler demand and expectations have too much influence on fisheries managers for there to be wide-spread change. The issue with convincing anglers to change their beliefs is that angler values, involvement, angling orientation,

[127] Carlin, Schroeder, and Fulton, "Site Choice among Minnesota Walleye Anglers: The Influence of Resource Conditions, Regulations and Catch Orientation on Lake Preference," 309.

and education are conflicting factors when it comes to angler support of alternative management strategies.[128]

Educating anglers on what their angling desires and habits might do to aquatic systems is one of the most appropriate actions for fisheries agencies. Offering anglers education that informs them about the impact they have on walleye and other fish populations, as well as how walleye catch rates influence angling pressure and how walleye populations respond to said angling pressure can both influence anglers on how to utilize fisheries for long-term use.[129] "Personal experiences can be an effective means of environmental education, so the most efficient efforts may include engaging anglers directly in habitat protection and restoration actions to ensure that anglers directly experience the positive effects of habitat improvements."[130] Getting anglers involved with fisheries managers doing projects that benefit the lake where they fish can expose them to environmental education and incentivize anglers to prioritize the health of their lakes. Providing personal experience will be the most effective educational tool in changing angler beliefs and motivations since engaging anglers in habitat restoration, lake protection, and other fishery-related projects have the best chance to persuade anglers on the positives of fisheries management and habitat improvement projects.[131] If fisheries managers can encourage realistic angler expectations – since many are reliant on stocking and have a goal of catching many large fish – while also maximizing opportunities to catch desired

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[128] Ibid., 310.
[129] Blackwell, Kaufman, and Moos, "Angler Exploitation of an Unexploited Walleye Population in the Northern Great Plains," 60.
[130] Schroeder et al., "The Influence of Angler Values, Involvement, Catch Orientation, Satisfaction, Agency Trust, and Demographics on Support for Habitat Protection and Restoration Versus Stocking in Publicly Managed Waters," 675.
[131] Ibid.

fish, then support for habitat protection and other management strategies may become more widely accepted.[132]

Emphasizing the importance of other species in aquatic systems is also important, as they all play a role in how well walleye can thrive in a system. Other species can also indicate the health of an aquatic system. Non-game species are equally as important to the ecosystem, as they play their respective role. Many anglers are only concerned with game species and associate non-game species as unimportant and even classify some species as "garbage fish."[133] These species are not traditionally thought to be of value to anglers, and many anglers lack the knowledge of these species in terms of their biological importance, how to catch them, or their utility.[134] Many of these species, however, are catchable and palatable and even have a large community following with interest in catching them, arguing that they are much more fun to catch due to their fight and their value to the biotic integrity.[135] Many of these species that are classified as non-game are palatable and have higher EPA and DHA and lower mercury levels than walleye.[136] These species have been subject to negative angler bias and assumptions, but educating anglers of their importance and even incentivizing catching them over walleye could increase angler awareness and interest in these species. Angler education can help reduce angler dependence on walleye and lead to more sustainable angling and diverse targeting of species instead of pressuring one species.

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132 Ibid.
133 Jake VanDeLaare, "Trash Fish' Don't Deserve Such a Bad Reputation," *wideopenspaces*, 2018.
134 Ibid.
135 Ibid.
136 Strandberg et al., "Spatial and Length-Dependent Variation of the Risks and Benefits of Consuming Walleye (*Sander Vitreus*)," 258.

Conclusion

The current angling culture is centered on walleye due to its historical and widely-accepted importance to anglers. Fisheries managers are influenced to prioritize efforts into managing these species in order to satisfy angler demand. Anglers have growingly become disconnected from the environment and the lake systems they fish on, forgetting that their actions and desires are not as important as the health of aquatic systems. The current walleye management strategies have been effective in most cases, but the future of walleye management and angling looks bleak. Anglers have forgotten their duty to respect and protect the lake systems they fish on and have pushed fisheries management and businesses to commodify lakes with a walleye fishery.

The future of lake health will be dependent on how well we act to mitigate outside influences on aquatic systems such as pollution, climate change, and the development of lakes. Lake health and the future of angling also depend on how anglers decide to react to declines in walleye abundances. If and when aquatic systems are no longer able to support the fish anglers prioritize due to placement of angler satisfaction over aquatic system health, lakes will lose their worth as biotic communities and as natural resources to humans. If we want to conserve our heritage of angling, particularly walleye angling, walleye anglers need to begin prioritizing habitat restoration efforts, diversify their targeted species, and modify their angling motivations. Fisheries managers' decisions will be reflective of angler interests, so if the angling culture can change to focus on lake health before their fishing goals, then anglers will continue to be able to enjoy their shared resource for years to come.

Shifting the culture with the assistance of fisheries management will allow anglers to still catch walleye but will also persuade anglers to catch other species and reconnect them with the

lake systems they fish on. Hopefully, angling will move away from aggressive, species-specific methods. This research was not meant to be anti-walleye, as this species is actually great for lake systems and are a great species for anglers to catch. However, the targeting of one species by 70 percent of anglers and the irresponsibility of many in doing so will be problematic for the future of angling and lake health in Minnesota. The state's massive fishing participation and economic benefits that rely on walleye are great, but this niche dependence on one species is unnecessary and will not be able to continue long into the future. Anglers and businesses that depend on walleye and walleye anglers do not need either to be successful, as there are so many other angling opportunities that this state's lakes can provide. These solutions are suggestions for keeping angling in Minnesota responsible and available for Minnesotans in the future. This will be difficult given the historical and cultural importance of walleye and the businesses and anglers that are centered on walleye angling, but modifying the angling culture now will benefit anglers, fisheries management, businesses, walleye, and lake systems in general when walleye abundances reach unsafe levels for angling.

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